McLean & Mathis

# A study of the influence, upon locomotive valve travel, of the deformations produced in the Stephenson gear by acceleration

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# A STUDY OF THE INFLUENCE, UPON LOCOMOTIVE VALVE TRAVEL, OF THE DEFORMATIONS PRODUCED IN THE STEPHENSON GEAR BY ACCELERATION

BY

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# THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

RAILWAY MECHANICAL ENGINEERING

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

John Crocker McLean and Victor Alvin Mathis

ENTITLED A STUDY OF THE INFLUENCE UPON LOCOMOTIVE VALVE TRAVEL, OF THE DEFORMATIONS PRODUCED IN THE STEPHENSON GEAR BY ACCELERATION.

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Railway Engineering

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# A STUDY OF THE INFLUENCE UPON LOCOMOTIVE VALVE TRAVEL OF THE DEFORMATIONS PRODUCED IN THE STEPHENSON GEAR BY ACCELERATION.

## INTRODUCTION.

It has long been known that, when a locomotive is moving slowly, the valve moves to the end of its stroke and remains there for an appreciable time while the lost motion in the gear is being taken up in the opposite direction. This delay during reversal is due largely to the resistance caused by the friction of the valve on its seat. As a result of inertia of the valve, this delay may disappear at high speeds. In the case of a valve which is moved by an eccentric, the principal effect of such distortions from the theoretical motion of the valve will be a change in the port opening produced. This will result in an increase or decrease of wire drawing.

The importance of a large port opening during the admission of steam and more especially near the point of cut-off is illustrated by the indicator card shown in Fig. 1. This card is reproduced from test No. 106 of a slide valve engine tested at the Louisiana Purchase Exposition. The speed, at the time this card was taken, was 160 revolutions per minute; and the cut-off was about 30 per cent. The excessive wire drawing of the steam as the velocity of the piston approaches its maximum is shown clearly. The effect of wire drawing may be illustrated further by reference to the chapter "Concerning Diameter of Driving Wheels" in "Locomotive Performance". In this chapter Dean Goss shows that of two locomotives which are similar with the exception of the size of the drivers,

the one with the larger drivers and consequent lower piston speed may be expected to develop a greater tractive power at high speed. The cause of the wire drawing shown by the indicator card may be seen in Fig. 2., in which the reduction in port opening--as the speed of the piston becomes high, is indicated clearly by the theoretical Zeuner circle. In this figure the dotted lines show the distortion which may be expected to result from lost motion. The crossed line represents the result of over travel which may be expected when the inertia of the parts overcomes the frictional resistance to their motion. In the curves which show the delay in the movement of the valve--due to friction--the chords of the Zeuner circle are shortened during acceleration and lengthened during deceleration by an amount equal to the assumed lost motion. When the valve has reached the end of its stroke and is standing still, these chords are of equal lengths and are shown in the figure by the arc CD drawn about O as a center with the constant length OC as a radius. It will be noted, especially in the case of overtravel of the valve caused by inertia and represented at the point D, that the form of the Zeuner diagram approaches the elliptical shape without a great increase in cut-off and with a reduced lead. This is the condition which has been much sought after by designers of other valve gears than the Stephenson. In the Stephenson gear "lead" is an indirect expression of port opening during admission, and the principal function of excessive lead at short cut-off, is to secure sufficient port opening throughout admission. Therefore, the question of a slight reduction in this excessive lead need not be considered when the matter of port opening during high piston velocity is considered directly.

## OBJECT.

It is the object of this thesis to investigate the distortion which actually occurs in the motion of the valve of Illinois Central Railroad Locomotive No. 2012, in such a manner as to enable us to arrive at some conclusions regarding the distortions which occur in the motion of a slide valve when the locomotive is running at sufficient speed to develope them.

## DESCRIPTION OF THE VALVE GEAR AND RUNNING GEAR OF THE ENGINE.

Type- 4- 6 - 0 (ten wheel)

Cylinders 19 1/2" x 26"

Diam. of Drivers-nominal--69"

" " " actual --68"

Valves, "American" Balanced slide valves

Valve dimensions-over all- 11" x 22 15/16"

Unbalanced area of valve at reversal during 3 1/2" stroke. --76 sq. inches.

Valve Gear, Stephenson, with transmission bar. Weight of parts ahead of the link block reduced to equivalent weight at valve rod.--350 lbs. Weight of parts back of the link block--Actual--149 lbs.

Eccentric radius -- 2 3/4"

## SERVICE AND CARE OF THE LOCOMOTIVE.

Locomotive No. 2012 is in daily service between Champaign and Centralia. It hauls a light local passenger train South and a heavy fast Pullman train back. There is an eight hour lay over at each terminal, and the engine is given a thorough inspection in each round house. No. 2012 has been out of the shops but about

three months, after having undergone a general overhauling.

## PREPARATION.

In order to obtain data for determining the variation in the events of the stroke, it is necessary to use a mechanism which will give a record of the occurence of the several events. It was at first proposed to take the data by means of an electrical apparatus so arranged as to record the events of the stroke by puncturing a moving paper by means of a spark, the circuits being completed by electrical contacts on the valve stem and crosshead. Valve ellipses were to be drawn through the points thus recorded. Another method proposed was to cause the engine--while running--to draw valve ellipses. This method was--at first--abandoned because of the assumed difficulty in designing a mechanism entirely free from lost motion within itself, but it was afterward adopted for the following reasons.

1. The high voltage required by the electrical method would be hard to control on a locomotive and might be dangerous.

2. Contacts, placed at--or near--the ends of the valve stroke and so arranged as to give two equal ordinates of an ellipse near the points of greatest port opening, would not define the distortion between these points where the distortion should be greatest.

A mechanism in which metallic contact is at all times maintained in the same direction, and which is therefore free from visible lost motion--was devised. This mechanism is shown by Fig. 3. It consists of a drum A, which is turned by a lever C, moved upwards by a sloping straight edge B, which is bolted to the crosshead of the locomotive. The lever is returned and contact between it and the

straight edge is maintained by the action of strong springs and bands whose tension is sufficient to overcome the effect of the inertia of the drum. The apparatus is mounted on the upper guide of the locomotive with the axis of the drum parallel to the axis of the locomotive cylinder. The motion of the drum is then similar to that of an indicator drum--when the latter is placed in a horizontal position. A sliding rod parallel to the axis of the drum and actuated by a clamp on the valve rod carried the pencil point D.

The rod was driven in each direction, but was provided with a double coil spring E to take up any invisible lost motion at the point of contact of the valve rod clamp.

On account of the weather, and in order to secure greater accuracy, sheets of tin were substituted for metallized record paper. These sheets of tim were wrapped entirely around the drum, and provision was made whereby the position--with regard to the pencil point--might be changed easily and quickly. This was done so that a number of records might be made on each sheet, since there was not time--at an ordinary station stop--to change the sheet. A hardened steel point, closely fitted to a long tube with its axis radial to the drum, bore lightly on the tin. A rope was so arranged that the operation of the mechanism could be stopped when desired. Operating the apparatus during a great many revolutions of the drivers will give an ellipse which automatically averagesthe separate ellipses and will show the maximum and minimum valve positions for all points of the stroke. Speeds were to be determined by referring to the speed record in the University Dynamometer Car. The point on the chart corresponding to the

location of the train was found by means of mile post records. The mechanism was carefully calibrated for piston position.Port lines were taken from the port marks on the valve stem.

## THE TESTS.

Two round trips were made to Centralia, and a number of diagrams were taken by the method outlined above.

## RESULTS AND COMPUTATIONS.

As stated above, the design of the mechanism provided for the automatic averaging of what would otherwise be a large number of tests on a single diagram. Several of the diagrams taken at moderate speeds are shown in Figs. 4, 5, and 6. These are copies of the actual diagrams which were made by the recording apparatus. In studying these diagrams it must be remembered that the mechanism drew ellipses in which the ordinates represent piston position, on a reduced scale, and the abscissae represent valve positions on a true scale, or full size.

They are introduced as a matter of interest only, as they show the delay in the reversal of the valve.

Figs. 7, 8, and 9 show corrected diagrams reduced to true proportions, at one fourth scale.

The abscissae represent piston position and the ordinates, the valve travel. Fig. 7 was taken at a speed of 22.8 miles per hour. The flattened upper and lower portions of the ellipse show the effect of friction in causing a delay at reversal. Fig. 8 was taken at a speed of 36.3 miles per hour. It also shows a restricted port opening due to lag, while in Fig 9.taken at 36.5 miles per hour, this lag di~~s~~sappears, giving an excessive port opening.

The Zeuner circle shown in Fig. 2 is based upon the valve gear dimensions of this engine. It is drawn through a cut off position of 34%, which is the cut-off indicated by the high speed ellipse. The maximum port opening is 3/4". That shown by Fig. 8 which shows valve delay is 5/8" and that shown by Fig. 9 is 7/8". This would indicate a lost motion each way of 1/8" or a total--when under the alternating strains due to inertia--of 1/4", or an average lost motion of 1/32" at each of the points at which it may occur. It is of interest to note that the port opening given by the Zeuner circle is the mean of that given by the two ellipses.

In the introduction it was shown that lost motion without inertia may be expected to cause excessive port opening near cut-off. Fig. 6 which shows valve delay does not show this. It is then to be concluded that any such excessive port opening due to delay of the valve in its return is only to be expected when the force, necessary to take up the lost motion completely, is great.

## THEORETICAL DISCUSSION.

In Fig. 10 the valve is reversing and the controlling eccentric is on its opposite dead center. The inertia of the entire valve gear tends to take up lost motion in a direction to favor over travel of the valve, or to move it farther to the right. The inertia of any one part tends to take up lost motion as far as its own controlling bearing, and that of any group of parts tends to take up the lost motion as far as the bearing or pin which actuates the group. Thus, the inertia of the valve, yoke, rod, rocker and transmission bar tends to take up the lost motion at the

link block. The inertia of the entire gear tends to take up lost motion to the eccentric, provided it is not first taken up at the link block or parts of it taken up at some intermediate bearings. The parts ahead of the block are actuated by a virtual eccentric, represented by the Zeuner circle and those behind by the actual controlling eccentric and its blade, slightly assisted or modified by the other. As stated in the description of the engine, the moment of the parts controlled by the virtual eccentric is equivalent to a weight at the valve rod of 350# and those behind the block weigh 148 lbs.

Henderson, in his "Locomotive Operation", shows that the inertia of the parts may be expressed as

$C = .00038\ G\ r\ N^2$ (formula 8)

in which

C = force

G = weight in lbs.

r = radius in ft. of crank or eccentric and

N = revolutions per minute.

Substituting our weight ahead of the block and assuming 2000 R. P. M. we have--with r =.17

$C = .00038 \times 350 \times .17 \times 40000 = 904$ lbs.

In tests of slide valve friction quoted, Henderson gives the coefficient of friction as varying from .04 to .07. Applying the latter value to the 76 sq. in. of unbalanced area of our valve we have--for a steamchest pressure of 150 lbs. $76 \times .07 \times 150 = 798$ lbs. frictional resistance. From this it will be seen that the effect of inertia in taking up lost motion at the link, and without the assistance of the eccentric strap and blade is 106 lbs. in

excess of the frictional resistance.

Remembering that when an engine receives a general overhauling the eccentric straps may be only "closed" without boring and without turning off the eccentrics, that--even when new--the straps are bored large, and that the location of wear generally favors lost motion when on dead center, we will see that the lost motion in the strap may be equal to that of all of the case hardened pins and surfaces combined, we may safely add the inertia of the strap and blade to that of the other parts, equate them to the frictional resistance and solve for the speed at which we may expect considerable over travel. In any event this should give us the speed at which to expect over travel to the extent of the lost motion at the eccentric. In equating to our assumed frictional resistance we are obliged to include the friction within the gear itself; very little is known of this value, but as the pins are reversing at the moment considered, it is believed that 12% of the valve friction will be liberal. This increases the frictional resistance, al~~l~~ready found, to 900 lbs. Substituting our values for the engine tested, and for the virtual eccentric corresponding to the card showing over travel of the valve, we have

$$C = .00038 \times 350 \times .15 \times N^2 + .00038 \times 149 \times .23 \times N^2 = 900$$

$$\text{or } N = \sqrt{\frac{900}{.00038\ (350 \times .15 + 149 \times .23)}} = 165 \text{ R. P. M.}$$

The actual number of revolutions per minute at which the over travel was indicated by the diagrams was 182.5 R. P. M.

## CONCLUSIONS.

A careful consideration of the tests and discussion results in the following conclusions.

In a locomotive with a Stephenson gear the amount of lost motion developed by fair speeds may amount to 1/8" each way or 1/4" total, representing a distortion from the theoretical motion as shown by the Zeuner diagram, of 1/8". In the case of a valve with low frictional resistance, such as a piston valve; but of considerable weight, over travel of the valve may exist at very moderate speeds. In the case of a valve with high frictional resistance, the lost motion--at speeds below that at which over travel occurs, will result in a decreased port opening during admission, the amount of decrease depending upon the lost motion in the gear.

In the case of piston valves at moderate speeds or of slide valves at high speeds, the inertia of the valve and gear causes an advantageous port opening during the latter part of admission when it is most desired. In either valve the effect of lost motion is to reduce port opening at low speed--and especially in the case of a slide valve--to reduce the acceleration of the train until such speed is attained as to result in over travel.

At high speed, the effect of inertia tends to change the motion of the valve from harmonic to elliptical, and of the form of Zeuner circle representing it, from circular to elliptical.


Test-106 160-34-F

Figure-1

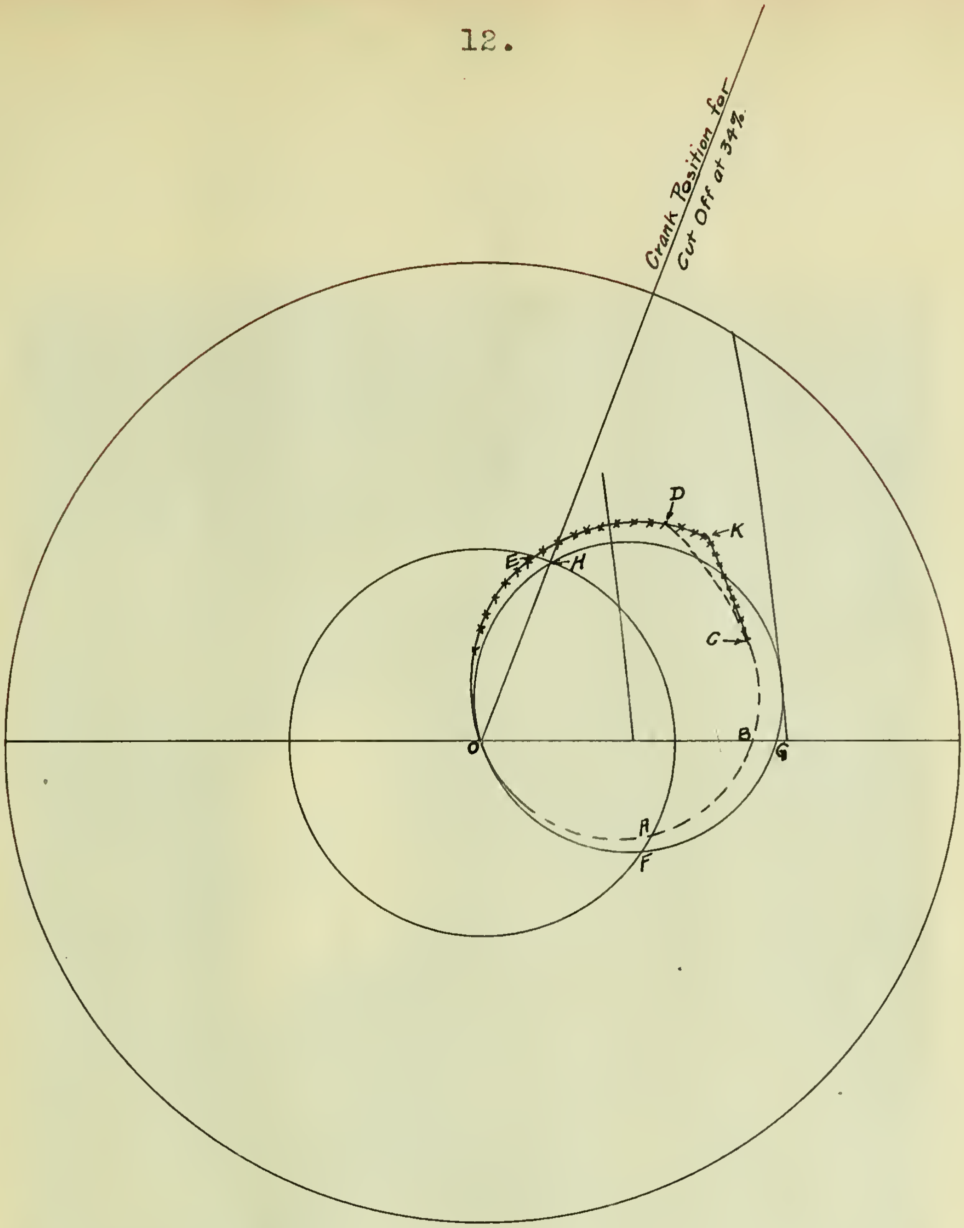



Figure 2.


Figure 3

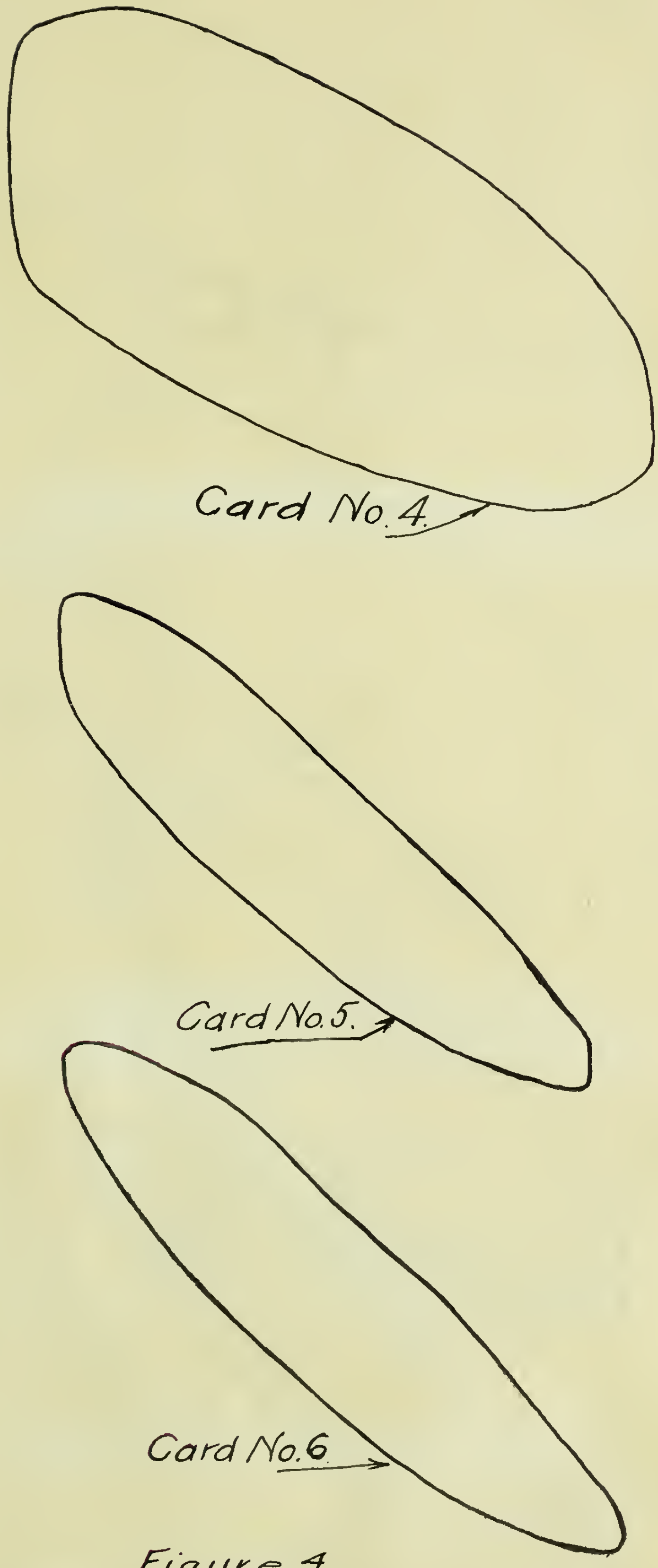



Figure 4.

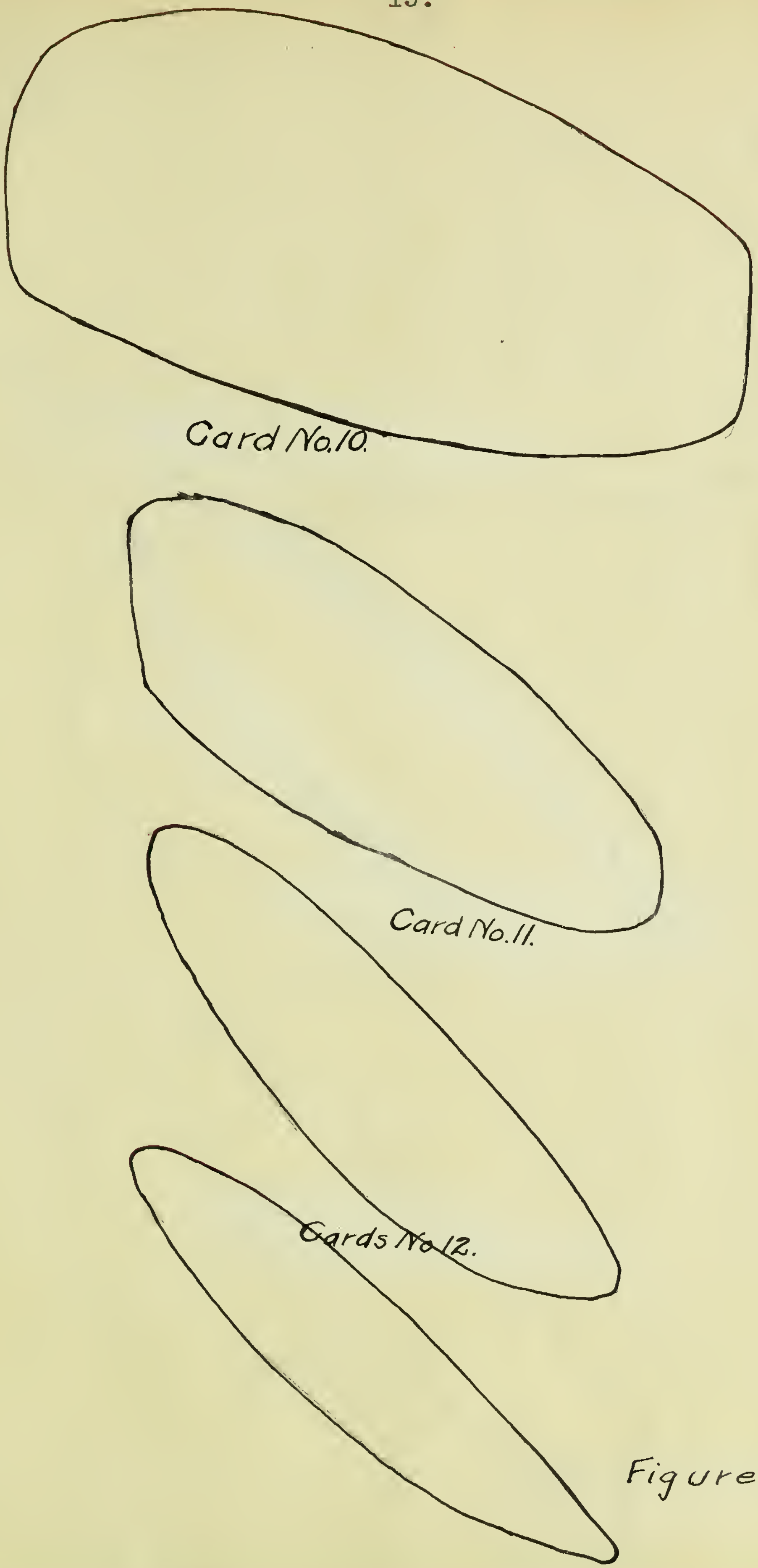
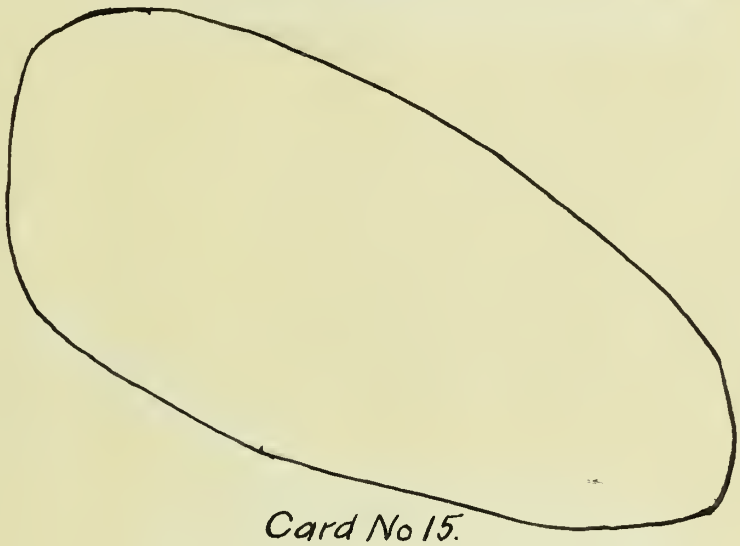



Figure 5

Card No.14.



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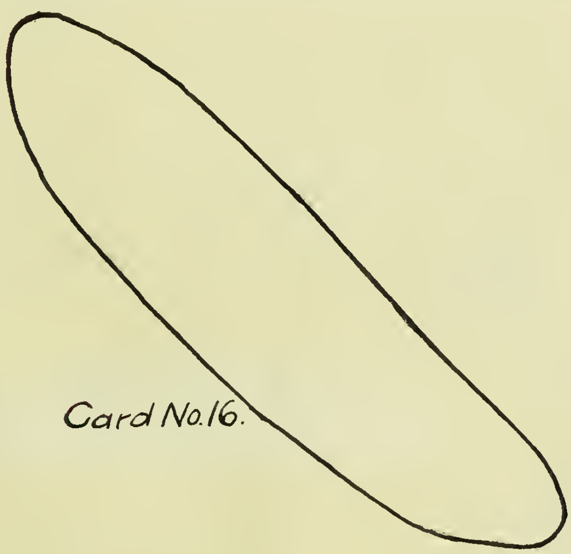

Card No.16.

Figure.6.

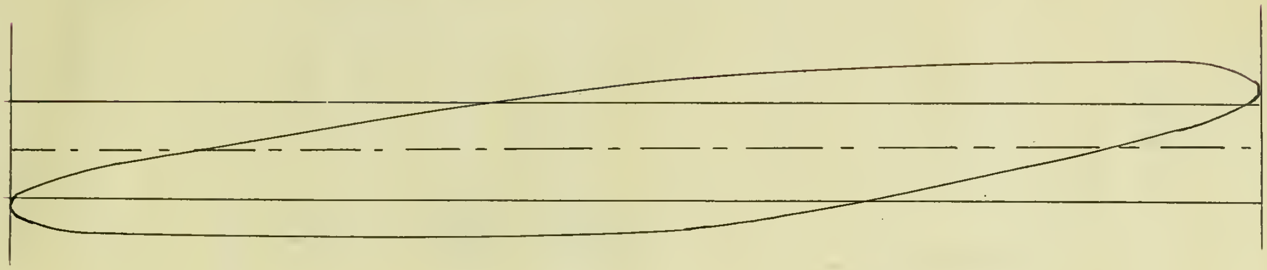

Figure. 7

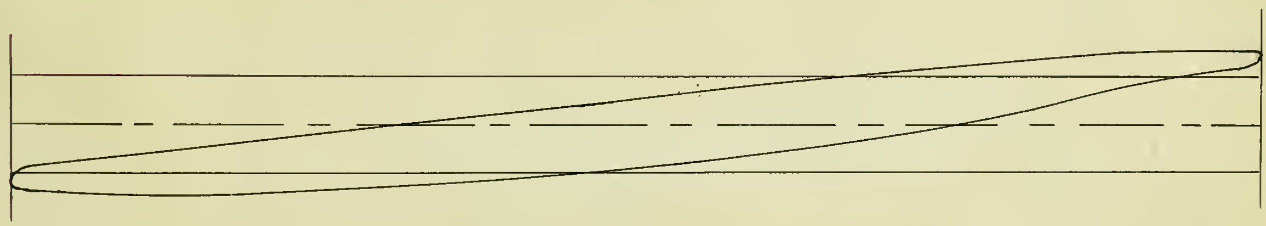

Figure 8

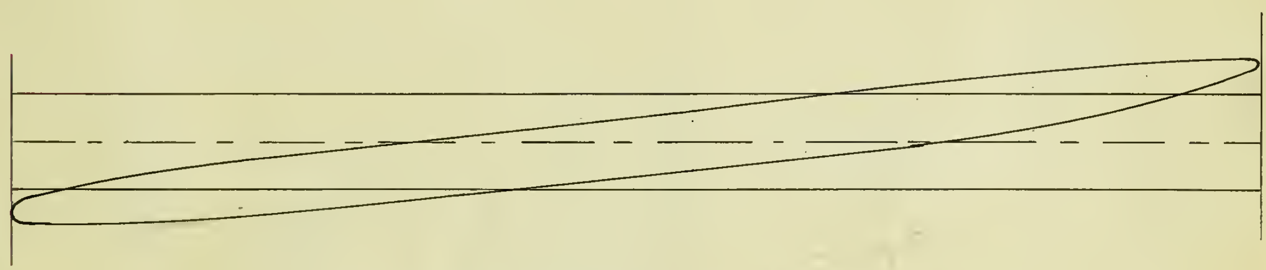

Figure 9

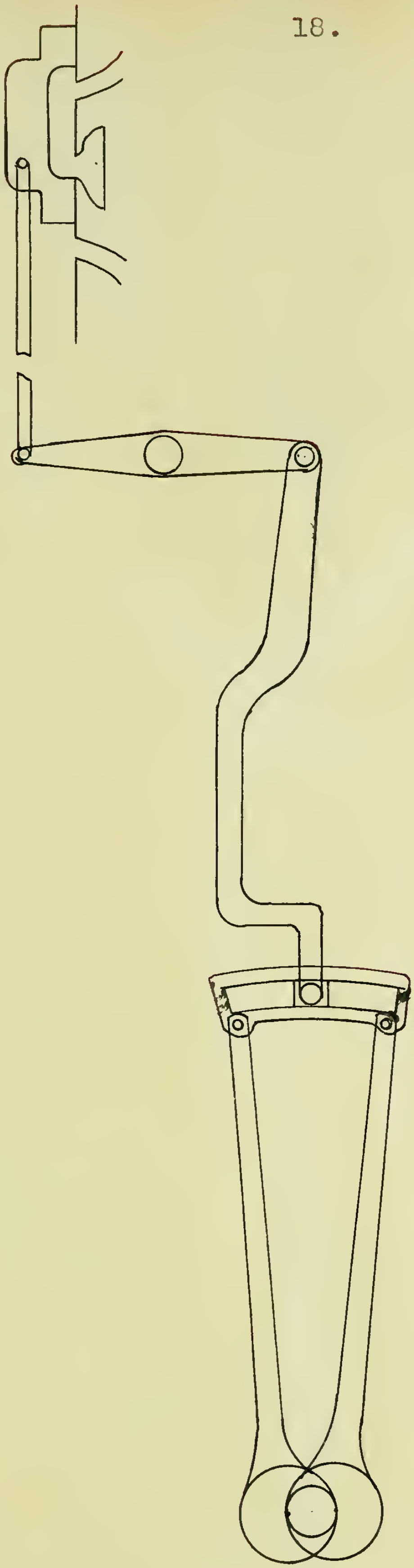

Figure-10